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Construction of Forced Vibration Generating Mechanism in a Chisel-Cultivator and its Kinematic Analysis

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Abstract: The developed working body is dedicated to the kinematic analysis of the construction of forced oscillating chisel-cultivator in an analytical method. As a result of the research, the analytical method of the movement of the joints of the mechanism generating forced vibrations was developed and its analysis was carried out.

Keywords: Mechanism, lever, curve, connecting rod, joint, joint, kinematic, analytical, analysis, vector, angle, speed, acceleration, analog, analysis, contour, leading, support.

Introduction: Currently, the task of the aggregate to prepare an energy-resource-efficient structure without reducing the quality of processing is to choose the mechanism that generates the vibration movement, taking into account the physical and mechanical properties of the soil, the direction of the vibration movement, the frequency and amplitude, and the transmission of the vibration movement to the working body through the links. should be determined rationally [1,2,3,4]. The kinematic analysis of the mechanism developed for this is one of the main processes.

As a result of the literature analysis and patent research, the construction of the mechanism generating forced vibrations used for soil cultivation was developed [5,6,7,8].

Research Method: Analytical solution methods for kinematic analysis of mechanisms are increasing, especially in recent years, with the help of analytical expressions connecting the kinematic and structural parameters of the mechanism, it is possible to create a calculation program and obtain the desired results [9].

It is convenient to use the method of vector contours in the analytical study of flat mechanisms. Therefore, we use this method in the kinematic analysis of the four-joint lever mechanism [10,11].

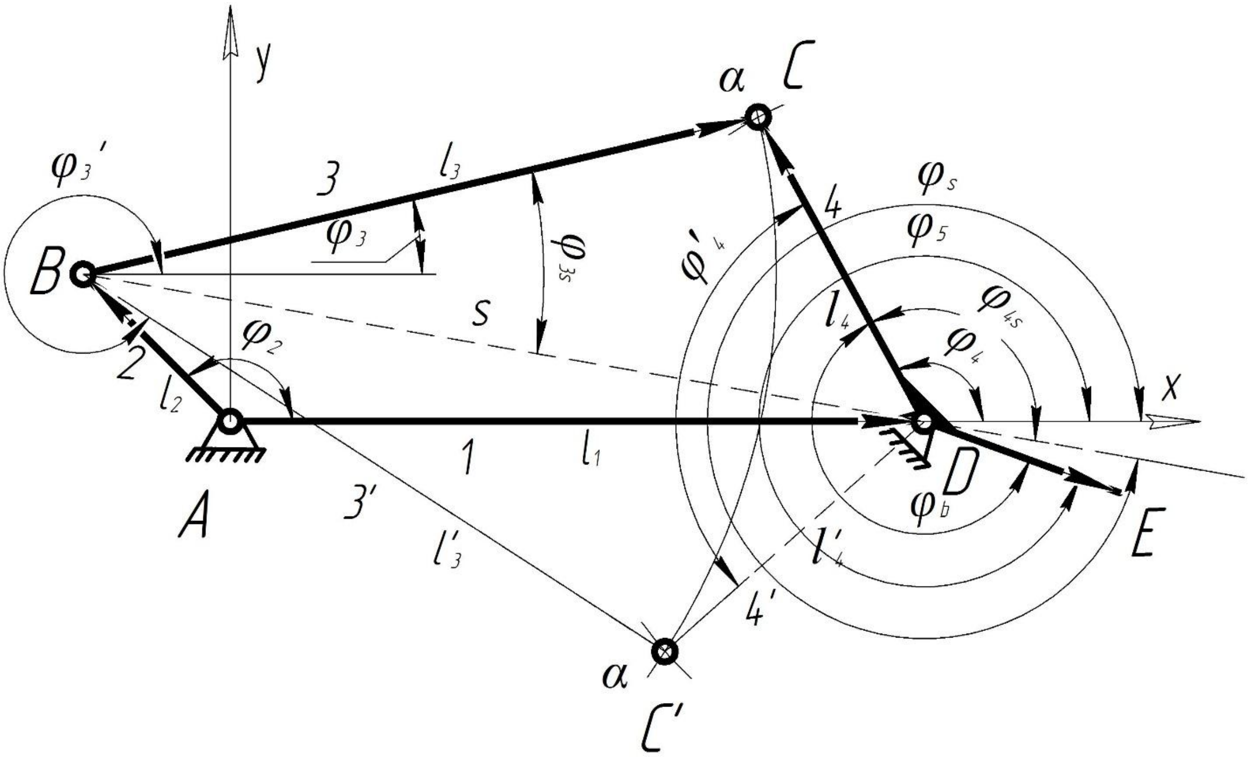

Figure 1. Four-joint lever mechanism with two vector contours

To construct the position of the leading link curvature of the four-link linkage mechanism at an angle φ_2, we place the fixed links at points *A* and *D* at a distance l_1 from the *x*-axis. The point *B* can be determined by placing *2* joint curvatures at a distance of l_2 to the fixed joint *A* at an angle of φ_2. By drawing arcs at a distance of l_3 from point *B* and at a distance of l_4 from point *D*, the point where the arcs meet can be determined as the location of points *C* in this case [11].

By connecting the *BCD* group consisting of links *3* and *4* and their leader *2* and base *1*, two symmetrical triangles *BCD* and *BC'D* can be formed relative to the straight line *BD* (Fig. 1).

Thus, it is possible to create two different four-joint articulated mechanisms *ABCD* and *ABC'D* in different ways. If the mechanism is assembled along the contour axis *ABC'D*, then the location of the 2nd, 3rd and 4th joints of the mechanism is determined by the angles φ_2, φ_3 and φ_4, respectively (Fig. 1). If the mechanism is assembled along the contour axis *ABCD*, then the position of the joints *2*, *3* and *4* of the mechanism is determined by the angles φ_2, φ_3 and φ_4, respectively. *BD* is a straight line and the angle φ_S of this straight line is common to both *ABCD* and *ABC`D* contours.

Analytical research of flat mechanisms is most convenient using the method of vector contours developed by V.A. Zinovev. Thus, it is convenient to determine the location of joints by dividing the closed contour *ABCD* shown in Figure 1 into two triangles *ABD* and *BCD* [12, 11]. In this way, the closed contour *ABC`D* can also be divided into two triangles *ABD* and *BC`D*. Then we construct the following vector equations for these contours:

ABD is for contour

$$\mathrm{l}_2 + s - l_1 = 0, \tag{2}$$

BCD for outline

$$\mathrm{l}_3 - l_4 - s = 0, \tag{3}$$

and *BC`D* for the contour

$$l_3' - l_4' - s = 0, \quad (4)$$

Here s is a modulo variable vector defining the positions of points *B* and *D*.

For the parameter in Figure 2, when traversing the contour clockwise, the letters in the contour occur in the order *BCDB*. This order of contour letters should be maintained for the full rotation of the 2nd syllable.

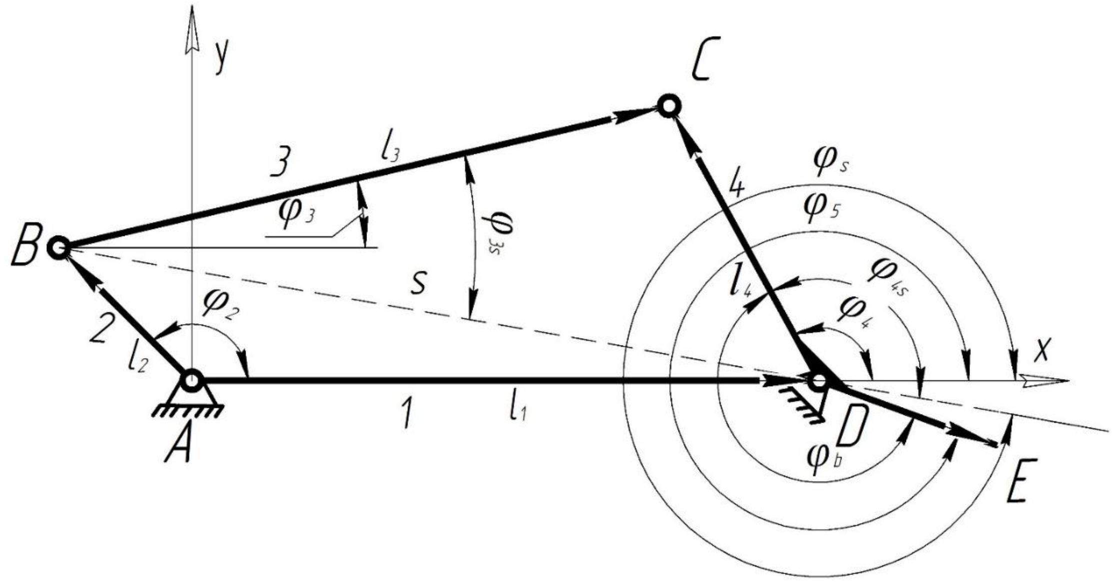

Figure 2. Determining the position of the joints of the four-joint lever mechanism

To determine the location of the joints of the four-joint mechanism, we project it onto the *Ax* and *Ay* coordinate axes (Fig. 2).

$$l_2 \cos\varphi_2 + s\cos\varphi_s - l_1 = 0 \quad (5)$$

and

$$l_2 \sin\varphi_2 + s\sin\varphi_s = 0 \quad (6)$$

From equations (5) and (6) we arrive at the following expression

$$tg\varphi_s = \frac{-l_2 \sin\varphi_2}{-l_2 \cos\varphi_2 + l_1}. \quad (7)$$

From the expression (7), the angle φ_s proportional to sin φ_2 and cos φ_2 in the quarter of the trigonometric circle is determined. From the expression (6), it is possible to determine the modulus vector s.

$$s = -l_2 \frac{\sin\varphi_2}{\sin\varphi_s}. \quad (8)$$

After that, we will consider the triangle *BCD*. We denote the angle of deviation of vectors l_3 and l_4 relative to the vector *s* by φ_{3s} and φ_{4s}.

Then the following two equations arise:

$$l_3^2 = l_4^2 + s^2 + 2l_4 s\cos\varphi_{4s} \quad (9)$$

and

$$l_4^2 = l_3^2 + s^2 - 2l_3 s \cos\varphi_{3s} \tag{10}$$

From equations (9) and (10), we determine the angles φ_{3s} and φ_{4s}.

$$\varphi_{4s} = \arccos\frac{l_3^2 - l_4^2 - s^2}{2l_4 s} \tag{11}$$

and

$$\varphi_{3s} = \arccos\frac{l_3^2 - l_4^2 - s^2}{2l_3 s} \tag{12}$$

The angles φ_{4s} and φ_{3s} can be negative or positive in general, that is, they satisfy both options. Since the *BCDB* option is being considered, the angles φ_{4s} and φ_{3s} have the same sign and the l_3 vector is always above the s vector.

$$\varphi_{4s} = \varphi_4 - \varphi_s \tag{13}$$

and

$$\varphi_{3s} = \varphi_3 - \varphi_s \tag{14}$$

from this

$$\varphi_4 = \varphi_{4s} + \varphi_s \tag{15}$$

and

$$\varphi_3 = \varphi_{3s} + \varphi_s\ . \tag{16}$$

Thus, if the lengths of the joints of the mechanism and the turning angle φ_2 of the 2nd joint are given, then the angles φ_3 and φ_4, that is, the states of the 3rd and 4th joints, can be determined for each position of the 2nd joint [11].

Let's consider the method of determining the angles φ_3 and φ_4 through intermediate functions φ_s , φ_{3s}, φ_{4s} and *s*.

It is not difficult to generate positional functions of joints *3* and *4*. For example: from equation (15) it is possible to derive the displacement function. Putting the values of φ_{4s} and φ_s from equations (11) and (7) into the above equation, we get the following equation.

$$\varphi_4 = \varphi_{4s} + \varphi_s = \arccos\frac{l_3^2 - l_4^2 - s^2}{2l_4 s} + arctg\frac{-l_2\sin\varphi_2}{-l_2\cos\varphi_2 + l_1}. \tag{17}$$

We put the value of s obtained from the triangle *ABD* into the equation (17) (Fig. 2).

$$s = \sqrt{l_1^2 + l_2^2 - 2l_1 l_2 \cos\varphi_2},$$

Then $\varphi_4 = \arccos\dfrac{l_3^2 + l_4^2 - 2l_1 l_2\cos\varphi_2}{2l_4\sqrt{l_1^2 + l_2^2 - 2l_1 l_2\cos\varphi_2}} + arctg\dfrac{-l_2\sin\varphi_2}{-l_2\cos\varphi_2 + l_1}.$ (18)

$\varphi_3 = \varphi_3(\varphi_2)$ the location function can also be derived in the same way [11].

Since the *DE* part of the 4th link differs from the *DC* part by an φ_b angle, its angle is determined as follows.

$$\varphi_5 = \varphi_4 + \varphi_b \qquad (19)$$

Based on the above, let's consider the *ABCD* mechanism with a four-joint hinge proposed in Figure 5.

Research results and discussion. If the length of the joints is equal to l_1= 0.723, l_2= 0.0075, l_3=0.69484, l_4=0.2, and the angle between the *AB* curve and the supports (relative to the *x* axis) is equal to φ_2=196°, then φ_3 of the 3rd and 4th joints of the *ABCD* mechanism relative to the support and we determine the angles φ_4.

Using equation (7), we get the following result

$$tg\varphi_s = \frac{-l_2 \sin\varphi_2}{-l_2\cos\varphi_2 + l_1} = \frac{-0.0075 \cdot \sin 196°}{-0.0075 \cdot \cos 196° + 0.723} = \frac{0.002}{0.73} = 0.284$$

Since the proportional *sin* φ_2 in the figure is negative, and the proportional *cos*φ_2 in the denominator is positive, it was found that the vector *s* is located in the fourth quadrant, so

φs =360°-0°10\`=359°50\`.

According to the equation (8), the modulus of the vector s:

$$s = \left| -l_2 \frac{\sin\varphi_2}{\sin\varphi_s} \right| = \left| -0.0075 \frac{\sin 196}{\sin(359°50`)} \right| = 0.730$$

φ_{4s} ва φ_{3s} бурчаклари (11) ва (12) тенгламалар ёрдамида топилади.

$$\cos\varphi_{4s} = \frac{l_3^2 - l_4^2 - s^2}{2l_4 s} = \frac{0.69484^2 - 0.2^2 - 0.730^2}{2 \cdot 0.2 \cdot 0.730} = 0.310$$

and

$$\cos\varphi_{3s} = \frac{l_3^2 - l_4^2 + s^2}{2l_3 s} = \frac{0.69484^2 - 0.2^2 - 0.730^2}{2 \cdot 0.69484 \cdot 0.730} = 0.962$$

Then, $\varphi_{4s}=108°$ ва $\varphi_{3s}=15°53`$. We define the angles φ_4 and φ_3 as follows:

$$\varphi_4 = \varphi_{4s} + \varphi_s = 108°-0°10`=107°50`$$

and

$$\varphi_3 = \varphi_{3s} + \varphi_s = 15°53`-0°10`=15°43`$$

To determine the velocities and accelerations of the joints of the four-joint articulated mechanism (Fig. 3), we construct the vector equation of the closed line *ABCD*. We have:

$$l_1 + l_2 + l_3 = l_4 \qquad (20)$$

Projecting this equation onto *Ax* and *Ay* axes, we derive the following expression:

and
$$\left. \begin{aligned} -l_1 + l_2\cos\varphi_2 + l_3\cos\varphi_3 &= l_4\cos\varphi_4 \\ l_2\sin\varphi_2 + l_3\sin\varphi_3 &= l_4\sin\varphi_4, \end{aligned} \right\} \qquad (21)$$

Here φ_2, φ_3 and φ_4 are joints *2*, *3* and *4* and angles relative to the *Ax* axis.

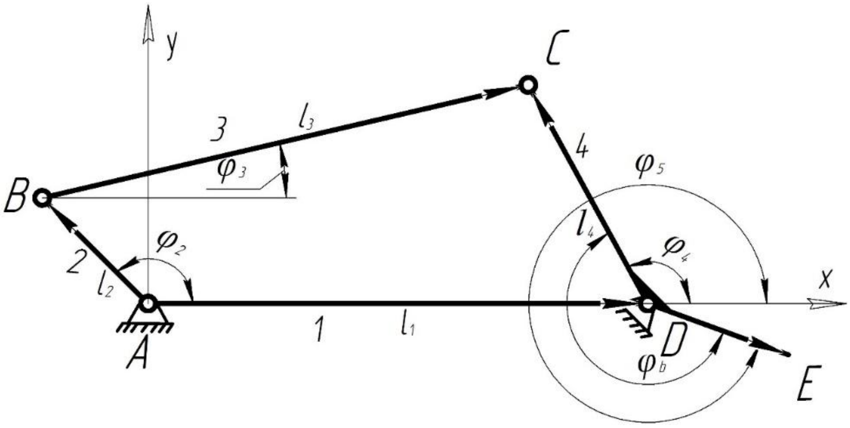

Figure 3. The scheme for determining the speed and acceleration of a four-joint articulated mechanism

We differentiate equation (21) to find the analog of angular velocity φ_3 and φ_4.

$$\left.\begin{aligned} -l_2\sin\varphi_2 - l_3\sin\varphi_3\frac{d\varphi_3}{d\varphi_2} = -l_4\sin\varphi_4\frac{d\varphi_4}{d\varphi_3}, \\ l_2\cos\varphi_2 + l_3\cos\varphi_3\frac{d\varphi_3}{d\varphi_2} = l_4\cos\varphi_4\frac{d\varphi_4}{d\varphi_2}. \end{aligned}\right\} \quad (22)$$

$d\varphi_3/d\varphi_2=i_{32}$ if we consider the analog of angular velocity ω_3 of joint *3*, then $d\varphi_4/d\varphi_2$-i_{42} is the analog of angular velocity ω_4 of joint *4* [11], then

$$\left.\begin{aligned} l_2\sin\varphi_2 + i_{32}l_3\sin\varphi_3 = i_{42}l_4\sin\varphi_4, \\ l_2\cos\varphi_2 + i_{32}l_3\cos\varphi_3 = i_{42}l_4\cos\varphi_4. \end{aligned}\right\} \quad (23)$$

Above mentioned i_{32} , i_{42} are equal to the ratio of ω_3 and ω_4 angular velocities and ω_2 angular velocity of the leading joint.

$$i_{32} = \frac{d\varphi_3}{d\varphi_2} = \frac{d\varphi_3/dt}{d\varphi_2/dt} = \frac{\omega_3}{\omega_2}$$

and

$$i_{42} = \frac{d\varphi_4}{d\varphi_2} = \frac{d\varphi_4/dt}{d\varphi_2/dt} = \frac{\omega_4}{\omega_2}.$$

Since the deflection of the *xAy* coordinate axis is equal to the total angle of φ_3, we subtract the angle φ_3 from the angles given in equation (23).

$$l_2\sin(\varphi_2-\varphi_3) = i_{42}l_4\sin(\varphi_4-\varphi_3),$$

From here we find the angular velocity ω_4 of the analog i_{42}

$$i_{42} = \frac{l_2\sin(\varphi_2-\varphi_3)}{l_4\sin(\varphi_4-\varphi_3)}. \quad (24)$$

As shown above, we find the angular velocity ω_3 of the analogue of i_{32}

$$i_{32} = -\frac{l_2\sin(\varphi_2-\varphi_4)}{l_3\sin(\varphi_3-\varphi_4)}. \quad (25)$$

To find the angular acceleration ε_4 and ε_3 of joints *3* and *4*, we get the following result by differentiating equation (23) on the coordinate φ_2.

$$\left.\begin{aligned} l_2\cos\varphi_2 + i_{32}^2 l_3\cos\varphi_3 + i'_{32} l_3\sin\varphi_3 = i_{42}^2 l_4\cos\varphi_4 + i'_{42} l_4\sin\varphi_4, \\ -l_2\sin\varphi_2 - i_{32}^2 l_3\sin\varphi_3 + i'_{32} l_3\cos\varphi_3 = -i_{42}^2 l_4\sin\varphi_4 + i'_{42} l_4\cos\varphi_4, \end{aligned}\right\} \quad (26)$$

where: i_{32} and i_{42} are analogs of angular velocity, $i`_{32}$ and $i`_{42}$ are analogs of angular acceleration.

We find the values of $i`_{22}$ and $i`_{42}$ as follows

$$i'_{42} = \frac{l_2\cos(\varphi_2-\varphi_3) + i_{32}^2 l_3 - i_{42}^2 l_4\cos(\varphi_4-\varphi_3)}{l_4\sin(\varphi_4-\varphi_3)}, \quad (27)$$

$$i'_{32} = \frac{l_2\cos(\varphi_2-\varphi_4) - i_{42}^2 l_4 + i_{32}^2 l_3\cos(\varphi_3-\varphi_4)}{-l_2\sin(\varphi_3-\varphi_4)}. \quad (28)$$

We find the angular velocity ω_3, ω_4 and angular acceleration ε_3, ε_4 of joints *3* and *4* based on the following formulas (29) and (30) [11]

$$\omega_k = \frac{d\varphi_k}{dt} = \frac{d\varphi_k}{d\varphi}\frac{d\varphi}{dt} = \omega\frac{d\varphi_k}{d\varphi} = \omega\omega_\varphi = \omega\varphi'_k, \quad (29)$$

$$\begin{aligned} \varepsilon_k &= \frac{d\omega_k}{dt} = \frac{d}{dt}(\omega\omega_\varphi) = \omega\frac{d\omega_\varphi}{dt} + \omega_\varphi\frac{d\omega}{dt} = \omega\frac{d\omega_\varphi}{d\varphi}\frac{d\varphi}{dt} + \omega_\varphi\frac{d\omega}{dt} = \\ &= \omega^2\frac{d\omega_\varphi}{d\varphi} + \varepsilon\omega_\varphi = \omega^2\varepsilon_\varphi + \varepsilon\omega_\varphi = \omega^2\varphi''_k + \varepsilon\varphi'_k. \end{aligned} \quad (30)$$

Based on this; $\omega_3 = \omega_2 \cdot i_{32}$, (31)

$\omega_4 = \omega_2 \cdot i_{42}$, (32)

$\varepsilon_3 = \omega_2^2 \cdot i'_{32} + \varepsilon_2 \cdot i_{32}$, (33)

$\varepsilon_4 = \omega_2^2 \cdot i'_{42} + \varepsilon_2 \cdot i_{42}$, (34)

where: ω_2 and ε_2 are the angular velocity and acceleration of the 2nd joint.

Based on the above expressions, the following graphs were obtained on the basis of its numerical solution for *8* cases of one rotation of the leading (*krivoship*) joint of the mechanism (*Figures 4-5*).

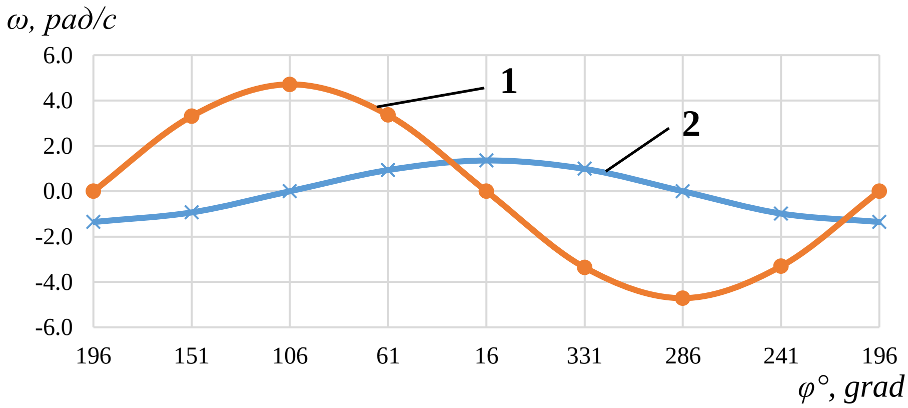

Figure 4. The dependence of the angular speed of points *C* and *E* of the mechanism on the angles of rotation of the leading (curveship) joint. *1-Angular velocity of point C, 2-Angular velocity of point E*

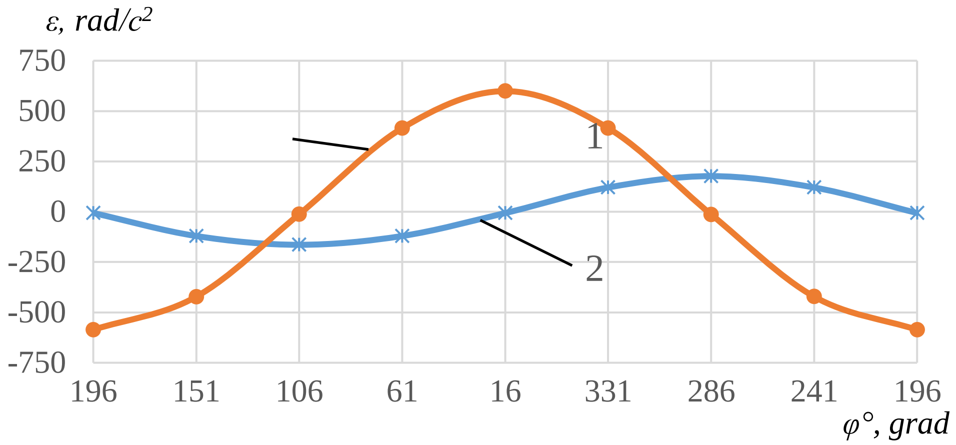

Figure 5. The dependence of the angular acceleration of points C and E of the mechanism on the angles of rotation of the leading (curveship) joint. *Angular acceleration of point 1-C, angular acceleration of point 2-E.*

Based on the above, we determine the speed and acceleration of points *B*, *C* and *E* of the mechanism using the following expressions.

$$V_B = \omega_2 \cdot l_2 \tag{35}$$

$$V_C = \omega_4 \cdot l_4 \tag{36}$$

$$V_E = \omega_4 \cdot l_{DE} \tag{37}$$

$$a_B = \varepsilon_2 \cdot l_2 \tag{38}$$

$$a_C = \varepsilon_4 \cdot l_4 \tag{39}$$

$$a_E = \varepsilon_4 \cdot l_{DE} \tag{40}$$

Based on the above expressions, the following graphs were obtained on the basis of its numerical solution for *8* cases of one rotation of the steering joint of the mechanism (*Figures 6-7*).

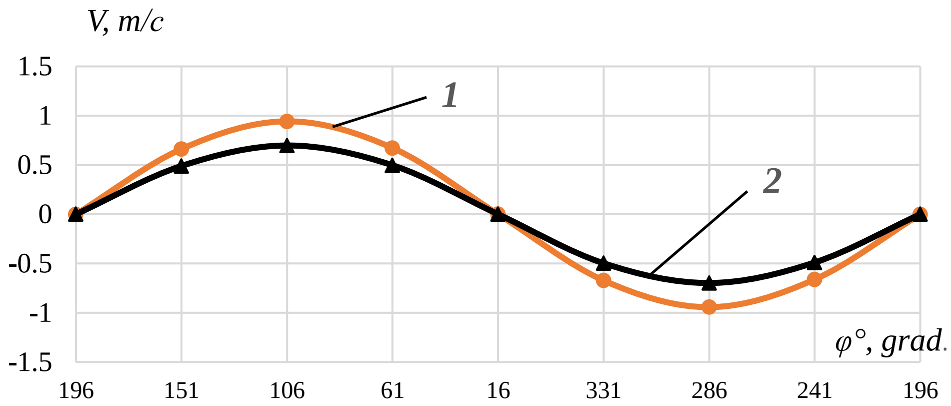

Figure 6. Dependence of the speed of points C and E of the mechanism on the angles of rotation of the leading (curveship) joint. *1-speed of point C, 2-speed of point E*

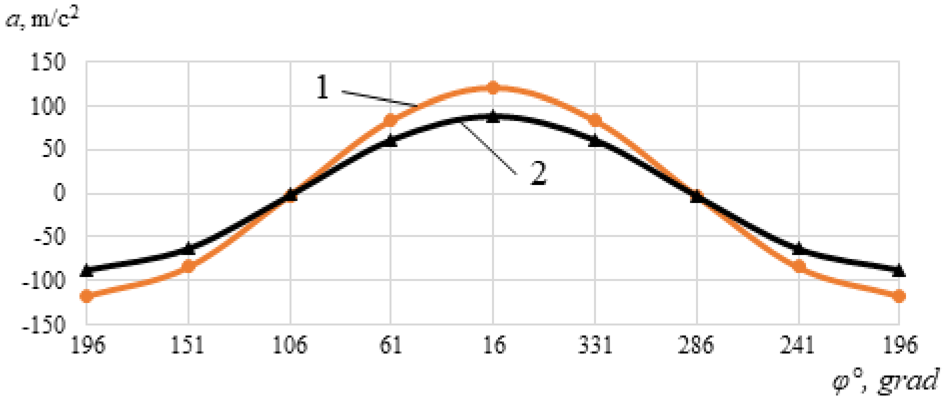

Figure 7. Dependence of the acceleration of points *C* and *E* of the mechanism on the angles of rotation of the leading (curveship) joint. *1 acceleration of point C, 2 acceleration of point E.*

Summary. Based on the above, the developed construction of the soil tillage device is highly efficient and its movement corresponds to the law of motion of the working body. In the analytical study of the mechanism, the information obtained from the kinematic analysis by the method of vector contours allows to check the next kinetostatics, dynamics and stability.

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